INTRODUCTION

It is well documented that sleep deprivation has a negative impact on cognitive performance (Durmer & Dinges 2005). Research also suggests that individuals typically need seven hours of sleep to maintain normal physiological function (Armstrong 2000). While the effects of sleep deprivation are well documented, its interaction with acute cold exposure is still unclear.

The relationship between sleep deprivation and thermoregulation has only recently come into focus. Castellani et al. (2003) examined shifts in body temperature threshold as a result of numerous detrimental factors (i.e., negative energy balance, sustained activity and sleep loss). They reported that during cold exposure following 84 hours of sustained operations, thermoregulatory variables including metabolic heat production, shivering threshold, respiratory exchange ratio and core temperature, were all lower than those exhibited during the control trial. Young et al. (1998) also utilized multiple stressors (i.e., negative energy balance, sleep deprivation and exertional fatigue) to examine soldiers’ ability to thermoregulate in a cold environment. They found that thermal sensation was more pronounced (soldiers felt colder) immediately following 61 days of military training as opposed to the recovery cold exposure trials (48 hours and 109 days post-training). Additionally, the acute effects of sleep deprivation were documented by a significant decrease in rectal temperature during the cold exposure following the training and to a lesser extent following 48 hours of recovery (Young et al. 1998).

More recently, Caine-Bish et al. (2005) examined the effects of acute cold exposure, following 33 hours of sleep deprivation, on hormone concentrations and metabolic rate. In contrast to Castellani et al. (2003) and Young et al. (1998), they observed no change in rectal and skin temperatures, heat production and thermal sensation due to sleep deprivation.

To date, little research has focused on the effects of sleep deprivation (> 36 hrs) in conjunction with acute cold exposure on cognitive function. Consequently, this study evaluated the cognitive impact of a repeated two hr cold challenge during 53 hrs without sleep.

METHODS

Eight healthy, young, non-smoking males volunteered to participate in this study. The subjects had a mean age of 22.8±1.7 yr, height (cm) of 178.6±11.9, mass of 81.0±10.0 kg, body fat (DXA) of 16.7±4.8% and VO₂ max of 43.8±7.9 ml·kg⁻¹·min⁻¹. Each subject completed two separate 60 hr trials in a counter-balanced design. In both trials volunteers reported to the lab at 2200 on the control day, having refrained from exercise and from consuming any alcohol or caffeine 24-hr prior to reporting, completed familiarization training, slept overnight in the laboratory (2200 – 0500) and then completed baseline tests (0530-0600). In each trial subjects
completed a 120 min Acute Cold Exposure (ACE) beginning at 0600 on each of three successive days. In the control trial (CON) volunteers slept between 2200-0500 on the second and third nights while in the sleep deprivation trial (SDEP) subjects were kept awake for 53 hrs following awakening after the control night. Subjects were awakened at 0500 (after control sleep for SDEP, all days CON), received a light breakfast, had skin thermistors applied and a rectal thermistor inserted 13-cm past the anal sphincter. Acute Cold Exposure (ACE) consisted of a 15 min baseline period (BASE) followed by 120 min of exposure to 10°C in a semi-reclined position wearing only shorts, socks and gloves in an environmentally controlled chamber (Neslab, Napa, California). This was followed by a two hr ambient recovery period (25°C for 2 h). The Gagge Thermal Sensation Scale (Gagge et al. 1967) a subjective measure of thermal sensation was administered at min 5 and 15 of BASE and at min 5, 15, 30, 45, 60, 75, 90, 105, and 120 during the ACE. The psychomotor vigilance task (PVT), a cognitive measure of sustained attention, was administered prior to and at 10, 30, 75, and 105 min of ACE. Each PVT was five min in duration with a random stimulus interval of 1-5 sec between presentations. The analysed measures include, reaction time (RT), minor (MIN, 500-999 msec) and major (MAJ, >1000 msec) lapses. For the duration of this paper, Day 1, 2 & 3 correspond to ACE 1, 2 & 3.

RESULTS
Rectal Temperature (T_{re})

Fig 1 illustrates the mean T_{re}, for CON vs SDEP in ACE 1, 2 & 3. There was a significant main effect for time in SDEP ACE 1, 2 & 3 (p≤0.05) and group (p=0.02) as average BASE T_{re} was significantly greater during SDEP than control. Two-way, repeated measures ANOVAs revealed a significant condition (CON vs SDEP) x time interaction for T_{re}, (p = 0.02). T_{re}, was significantly higher (p <0.05) in SDEP vs. CON at BASE and min 5 and 15 of ACE during Stage 2 of ACE and approached significance for the same time points in ACE 3 (p=0.07).
Mean Skin Temperature ($T_{sk}$)

As expected there was a significant main effect for time ($p \leq 0.001$) for all three ACE stages regardless of condition. A significant overall condition x time interaction was observed ($p=0.02$), however, post hoc analyses revealed no significant differences between conditions at any time point.

Thermal Sensation – Gagge Scale (TS)

There was a significant condition x time interaction ($p=0.05$), as well as a significant stage x time interaction ($p=0.02$) for thermal sensation (Gagge Scale) with SDEP reporting feeling colder in comparison to CON trial ($p=0.01$). Additionally, a significant main effect for time was also observed ($p \leq 0.001$).

PVT Performance

Mean reaction time on the psychomotor vigilance task (PVT) for each test in ACE 1, 2 & 3 for CON and SDEP is presented in Fig 2. There was a significant main effect for condition, stage and time ($p \leq 0.05$). SDEP resulted in a significant increase in RT which was exacerbated by ACE seen as a significant condition x stage interaction ($p=0.05$).

As shown in Fig 3, minor lapses (response time $\geq 0.5$ sec) on the PVT are presented for CON and ACE 1, 2 & 3. There were significant main effects for condition ($p=0.01$), stage ($p=0.02$) and a significant condition x stage interaction ($p=0.04$).
Fig 4 illustrates the mean number of MAJL (response time $\geq 1.0$ sec) during each PVT in CON and ACE 1, 2 & 3. There was a main effect of time across all three ACE stages ($p=0.00$), indicating that as time in the cold increased MAJL increased regardless of condition (SDEP, CON). Main effects for time ($p\leq 0.02$) and stage ($p=0.04$) were also identified in SDEP but not in CON. Interactions for condition x stage ($p=0.02$) and stage x time ($p=0.02$) were also identified. A separate two-way (condition x stage) ANOVA revealed a significant condition x stage interaction ($p=0.05$) resulting from a significant increase in MAJL in SDEP as compared to CON. In SDEP there was also a main effect for both stage and time ($p\leq 0.02$) which was not seen in CON.
CONCLUSIONS

SDEP had a significant impact on $T_{re}$, which was seen as an increase in baseline core temperature on days 2 & 3. This increase was mitigated during ACE on Days 2 & 3. From these data, it appears that SDEP affects an individual’s thermoregulatory response in a cold environment as the sleep deprived volunteers exhibited a higher $T_{re}$ than during the control trial. Core temperature did not significantly decrease during the two hr cold air challenge for either group on any of the three days, however subjective cold scales (i.e., thermal sensation) demonstrated an increase in the perception of cold in SDEP as time in the cold increased. All categories of PVT variables degraded during the cold exposure for both treatments. However, SDEP resulted in a significant interaction effect (treatment x time) for minor lapses (SDEP > CON). Post Hoc analyses also identified a significant increase in both minor and major lapses on day 3 in SDEP as compared to CON.

The results of this study demonstrate that exposure to cold, on three successive days, had no significant effect on performance of a sustained attention task in individuals who were not sleep deprived (CON). However, SDEP in combination with cold exposure resulted in a significant decrement in reaction time and increased the number of minor and major lapses. In addition, these decrements increased as a function of increasing time awake. However, the treatment by time interaction demonstrates that increasing time awake interacted with the cold exposure resulting in even greater performance decrements. The lack of a decline in core temperature during the cold exposures suggests that the individual was able to maintain temperature homeostasis. Anecdotal staff reports of subject shivering suggest that this may have had a negative impact on performance; however additional reports suggest that SDEP subjects began experiencing micro-sleep with greater frequency as time awake and time in the cold increase. In conclusion, SDEP had a significant negative impact on sustained attention which was further exacerbated by acute exposure to the cold.

REFERENCES